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FLIGHT TESTS OF A WIDE-ANGLE,  
INDIRECT OPTICAL VIEWING SYSTEM  
IN A HIGH-PERFORMANCE JET AIRCRAFT

*by Garrison P. Layton, Jr., and William H. Dana*

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Edwards, Calif.*

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# FLIGHT TESTS OF A WIDE-ANGLE, INDIRECT OPTICAL VIEWING SYSTEM IN A HIGH-PERFORMANCE JET AIRCRAFT

By Garrison P. Layton, Jr., and William H. Dana  
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## SUMMARY

A wide-angle, indirect optical viewing system was qualitatively evaluated in an F-104B aircraft as a means of providing visual reference to the pilot. Safe and acceptable performance using the indirect viewing system was demonstrated for all phases of daytime visual flight. Landings were performed in both the conventional and low lift-drag-ratio configurations. When the horizon was in the field of view, aircraft attitude sensing with the optics was satisfactory about all axes except pitch attitude in climbing flight. This degraded pitch-attitude sensing was due to the poor resolution at the bottom of the field and the lack of view to the sides.

A night flight was also performed. The system, in its present form, was considered unacceptable for this use because of large light losses and degraded resolution.

It was evident in the study that additional view directly to the side is required for performing circling approaches.

## INTRODUCTION

A major problem in the design of modern aerospace vehicles such as the supersonic transport and lifting reentry bodies is the provision of adequate exterior visual reference for the pilot. Because of various geometric and aerodynamic constraints, the use of conventional windows in these vehicles to provide the necessary visual references is impractical. The NASA Flight Research Center has undertaken a comprehensive program to define an indirect optical viewing system with which a pilot will feel comfortable and confident in performing all normal flight maneuvers. In the initial phase of the program, an indirect viewing system was investigated in a low-speed airplane (ref. 1). The investigation was then extended to an evaluation of an indirect viewing system in an F-104B high-performance jet aircraft (fig. 1). This paper presents the qualitative results of this evaluation.

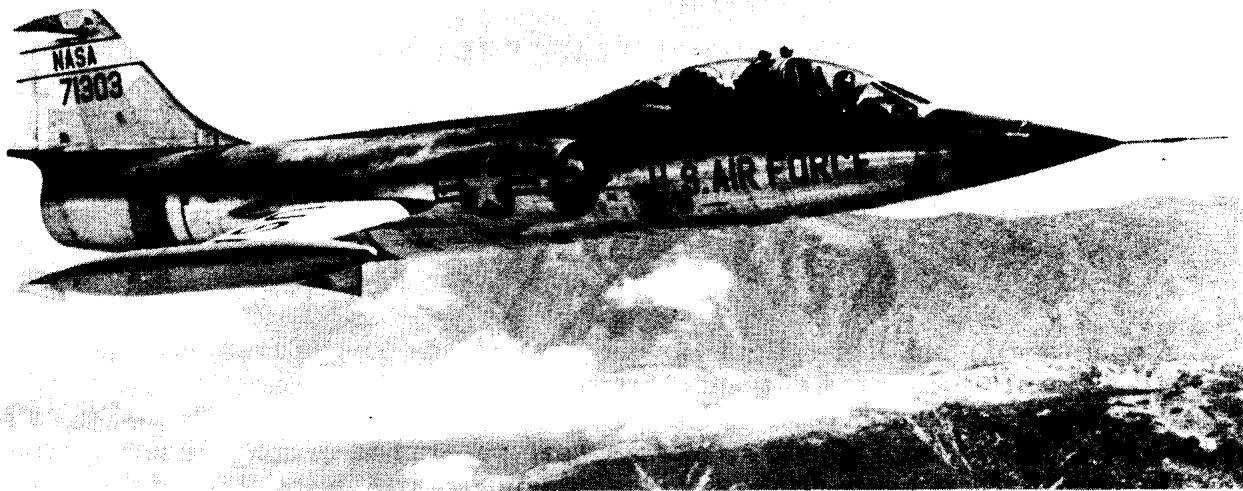


Figure 1.— F-104B test aircraft.

## SYMBOLS

The units used for the physical quantities in this paper are given in the U. S. Customary Units and, parenthetically, in the International System of Units (SI). Factors relating the two systems are presented in reference 2.

$g$	acceleration due to gravity, feet/second <sup>2</sup> (meters/second <sup>2</sup> )
$L$	distance from eyes to object, feet (meters)
$S$	one-half of optical separation, feet (meters)
$t$	time, seconds
$V$	velocity, feet/second (meters/second)
$\alpha$	eye-convergence angle, degrees (radians)

## DESCRIPTION OF THE OPTICAL SYSTEM AND INSTALLATION

### Optical System

The optical system tested (fig. 2) consisted of two wide-angle periscopes, each giving a  $90^\circ$  ( $\frac{\pi}{2}$  radian) circular field of view (fig. 3). The magnification was 1:1,

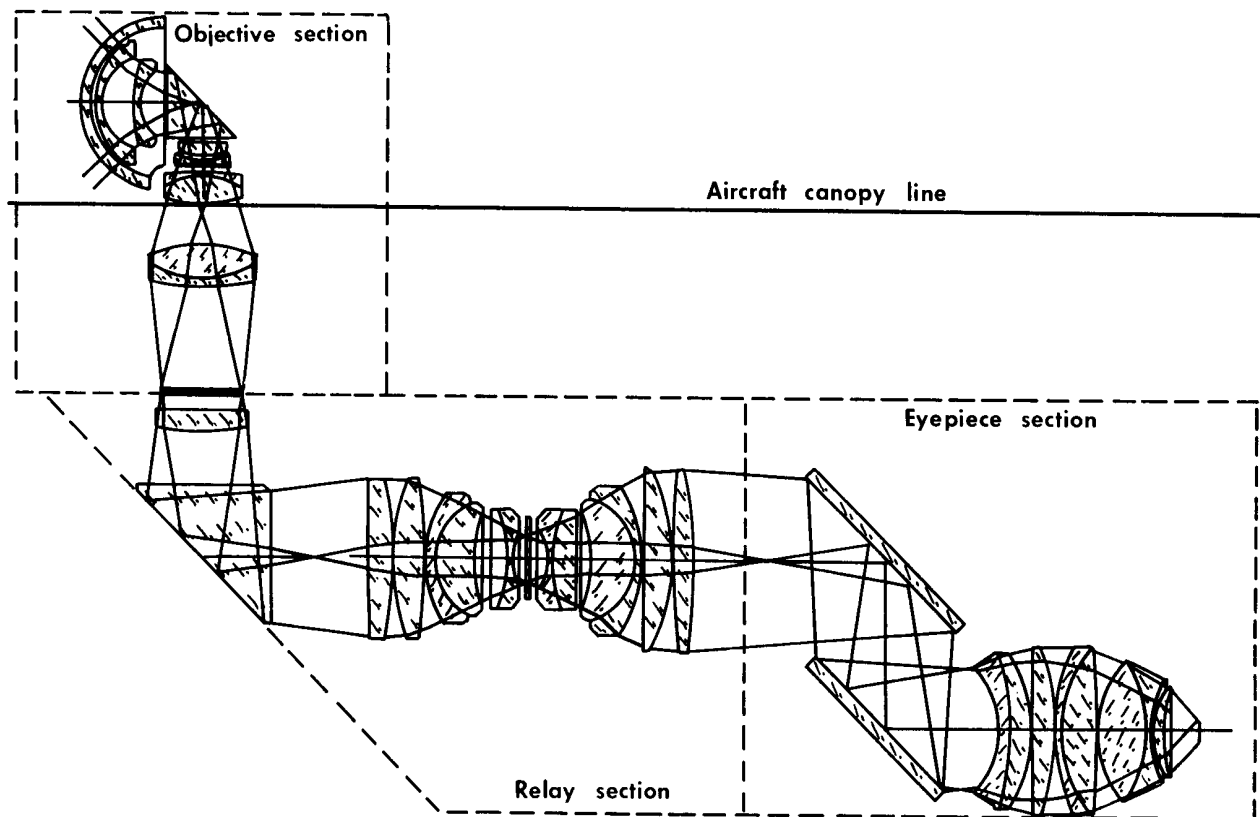


Figure 2.— Optical layout of the system.

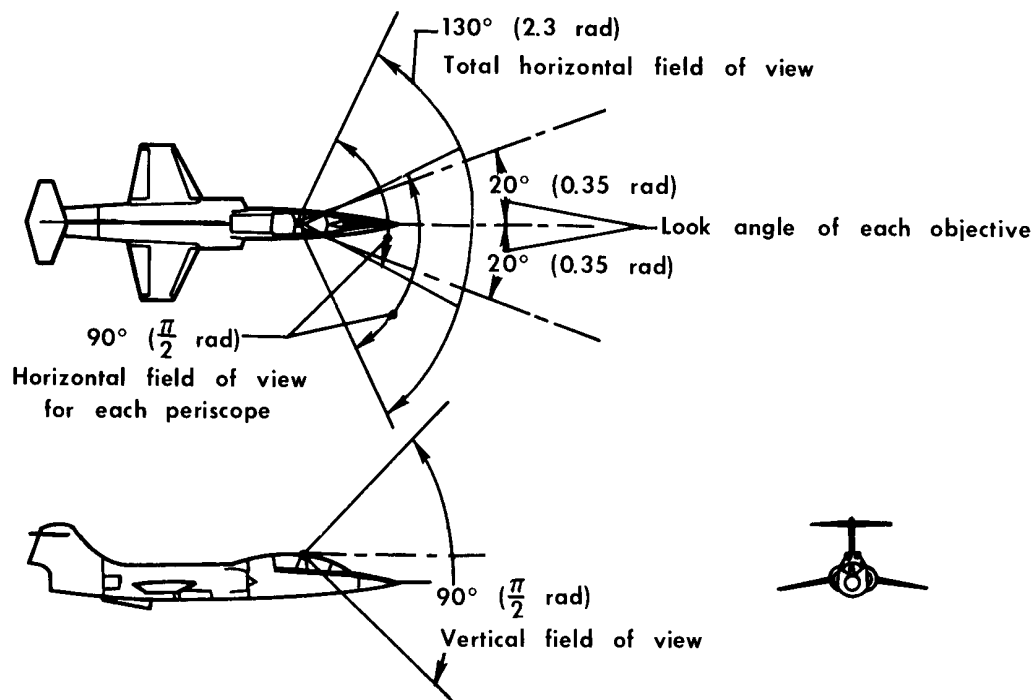


Figure 3.— Three-view of test aircraft showing field of view.

which provided true direction of objects within the field of view. The observer's eyes were effectively at the optical objective location on top of the aircraft with 15 inches (0.38 meter) of horizontal separation, as shown in figures 1 and 2. This arrangement produced an elevated, stereoscopically exaggerated view of the outside world, as

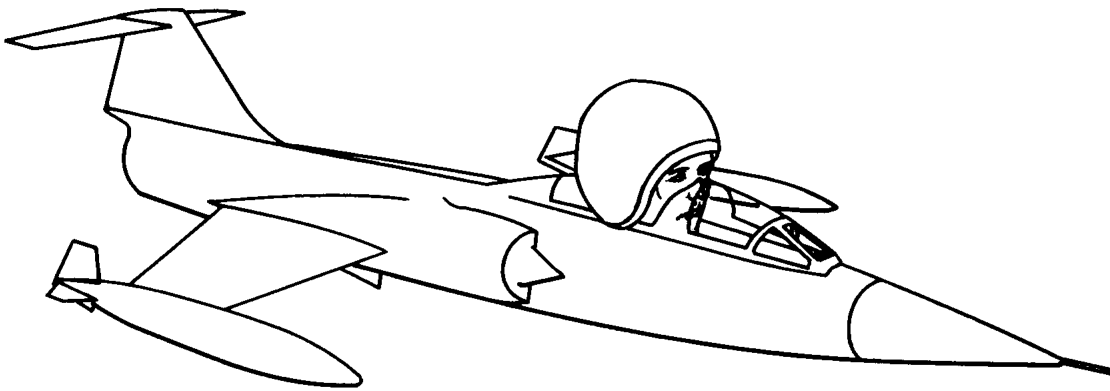


Figure 4.— Subjective impression of enhanced stereopsis.

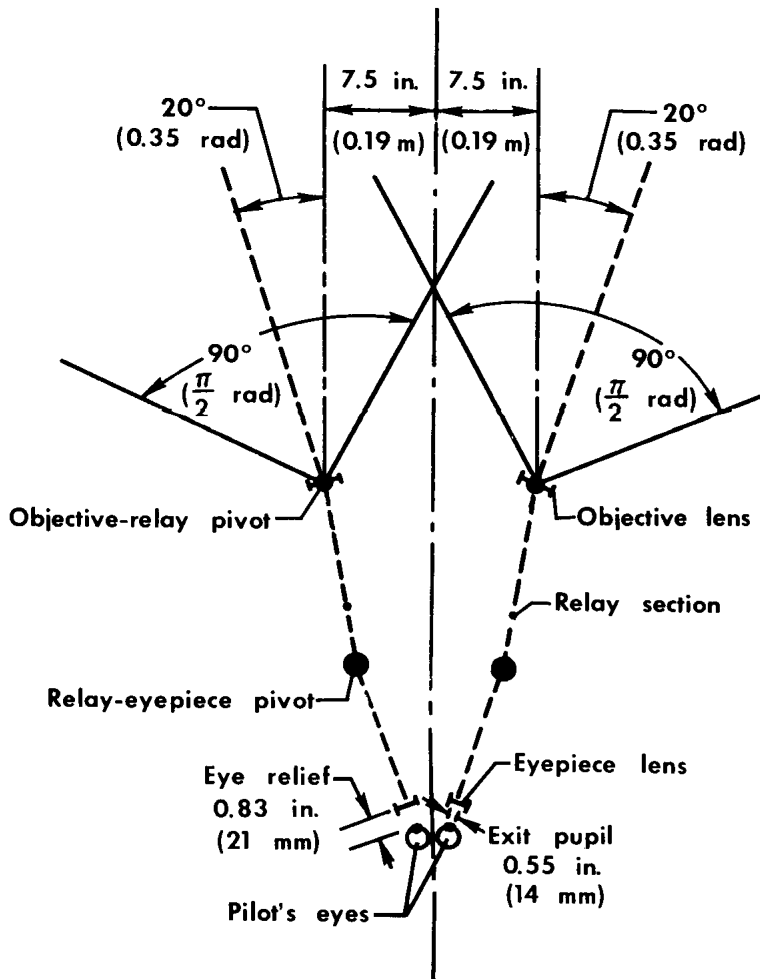


Figure 5.— Optical-system schematic.

shown in figure 4. In use, the system did not permit head movement, inasmuch as the pilot's eyes had to be looking straight forward, with an eye relief of approximately 0.83 inch (21 millimeters) (fig. 5). The exit pupils were 0.55 inch (14 millimeters) in diameter, just large enough to permit normal eye rotation without loss of the field of view. The separation of the exit pupils was adjustable so that the best fit could be obtained for each pilot's interpupillary separation.

The optical characteristics of the system tested can be assessed in terms of field error (barrel and pincushion distortion), lateral color aberration, and resolution. The field error was very small and could be observed only by moving the eye rapidly across the field. Since the system progressed from a small amount of barrel distortion at the center to a slight pincushion distortion at the outside of the field, small artificial rotations and velocity differences could be

detected. Field error was, however, completely unnoticeable when the aircraft was moving, as a result of the masking effect of normal aircraft vibrations.

Lateral color aberrations were also unobservable with the aircraft in motion. This aberration was negligible for objects infinitely far away and became increasingly apparent for closer objects. For an object 20 feet (6.1 meters) away, both red-green fringes and yellow-blue fringes could be observed, depending on eye location and angle of viewing into the system.

Resolution was essentially that of the normal eye for the center  $45^\circ$  ( $\frac{\pi}{4}$  radian) of each periscope. The outer part of each field of view had a noticeable deterioration; however, this was largely dependent on eye position. The separation of the two periscopes was adjusted to give the pilot the best possible resolution in the overlap area with the eyes looking straight ahead, at some expense to resolution at the edges of the field of view. In particular, the side portions of the field of view tended to have poor resolution to the extent that they were useful only for recognition and not detailed viewing. This was not predominantly a fault of the optical system, however, since it is not possible for the eyes to see clearly to the side without head rotation, even under normal conditions.

In addition to the preceding characteristics, the system had approximately 13-percent transmittance, which is similar to that of sunglasses, and the field appeared slightly yellow.

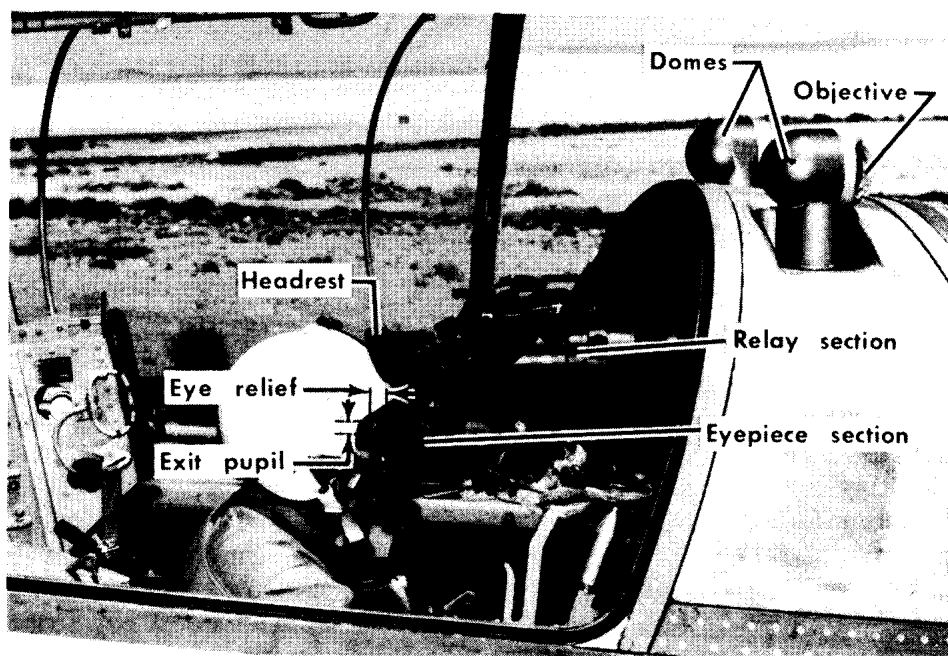
The optics were adjusted to provide a total field of view of  $130^\circ$  by  $90^\circ$  ( $2.3$  radians by  $\frac{\pi}{2}$  radian) by aiming the objectives  $20^\circ$  ( $0.35$  radian) to the side of the fuselage centerline (fig. 3), thus providing an overlap area of  $50^\circ$  ( $0.87$  radian) centered about the fuselage centerline. The aiming angle, however, could be varied from  $8^\circ$  to  $35^\circ$  ( $0.14$  radian to  $0.61$  radian). The  $20^\circ$  ( $0.35$  radian) aiming angle selected was less than was considered necessary in the investigation of reference 1 but, in order to obtain the clearest possible vision in the overlap area, was more nearly optimum for the optics evaluated in this study.

### Installation

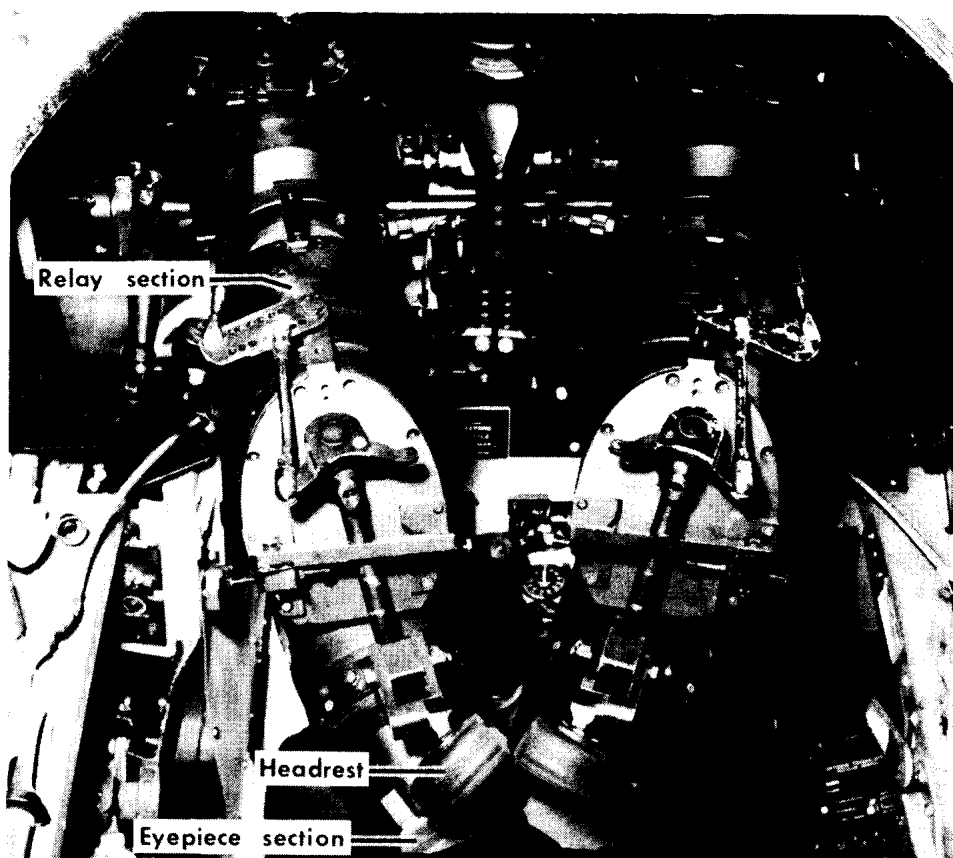
The optics were mounted to a modified sheet-aluminum center-section canopy to provide indirect vision to the pilot in the rear seat (figs. 6(a) and 6(b)). The system was adjusted to yield the view angles shown in figure 5 and mechanized to provide both variable overlap angles and variable interpupillary distances. This flexibility necessitated having both the eyepiece and relay section angles adjustable.

To provide the pilot with sufficient information with which to fly the aircraft, basic flight information--airspeed, altitude, and power setting--was presented on a modified center panel (fig. 7).

Inasmuch as the F-104B airplane is fitted with ejection seats, it was necessary for the optical system to clear the ejection envelope in the event of an emergency.



(a) Side view.



(b) Rear view.

Figure 6.— Optics in viewing position.



This was accomplished by pneumatically folding the optics downward from a hinge point at the forward end of the relay section (fig. 7).

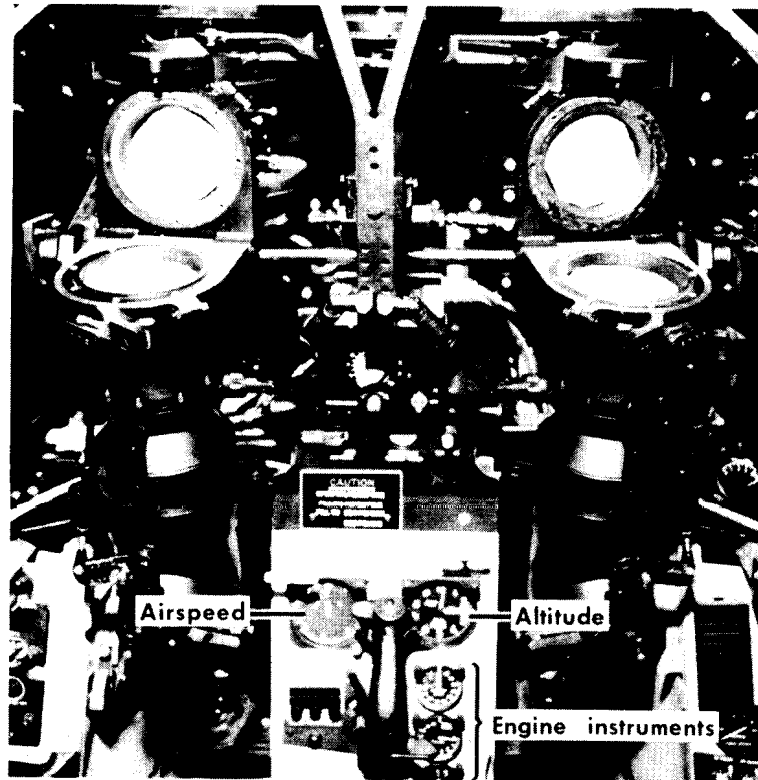


Figure 7.— Pilot's instrument panel and folded optics.

## EVALUATION PROCEDURE AND TEST FLIGHTS

The evaluation procedure was strictly qualitative, with no attempt to obtain numerical data except for pilot estimates of touchdown error and height misjudgment. A safety pilot was in the front seat on all flights to take notes and corrective action when necessary.

Five pilots in the program each flew two flights to evaluate the system. One other pilot flew one flight. On each of the flights a series of low lift-drag-ratio approaches was made to the dry lakebed runway at Edwards Air Force Base, with about 25 percent of the approaches carried to touchdown. The low lift-drag-ratio approaches (fig. 8) were made with 77-percent power and an indicated airspeed of 300 knots (150 meters/second), which yielded a lift-drag ratio of 4. The total time for this maneuver was approximately 2 minutes from high key at an altitude of 25,000 feet to 30,000 feet (7.6 kilometers to 9.2 kilometers) to touchdown. After these maneuvers

were completed, a series of conventional power-on landings was made on the runway (fig. 9).

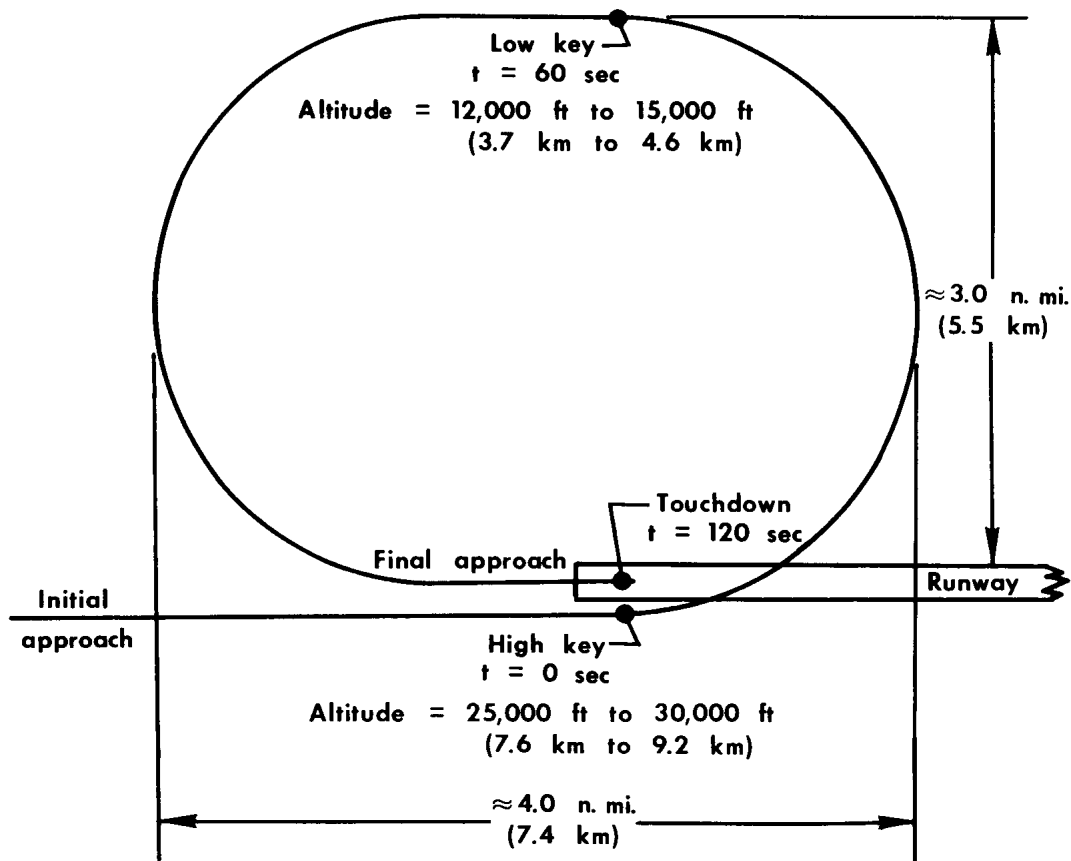


Figure 8.—Circling low lift-drag-ratio approach.

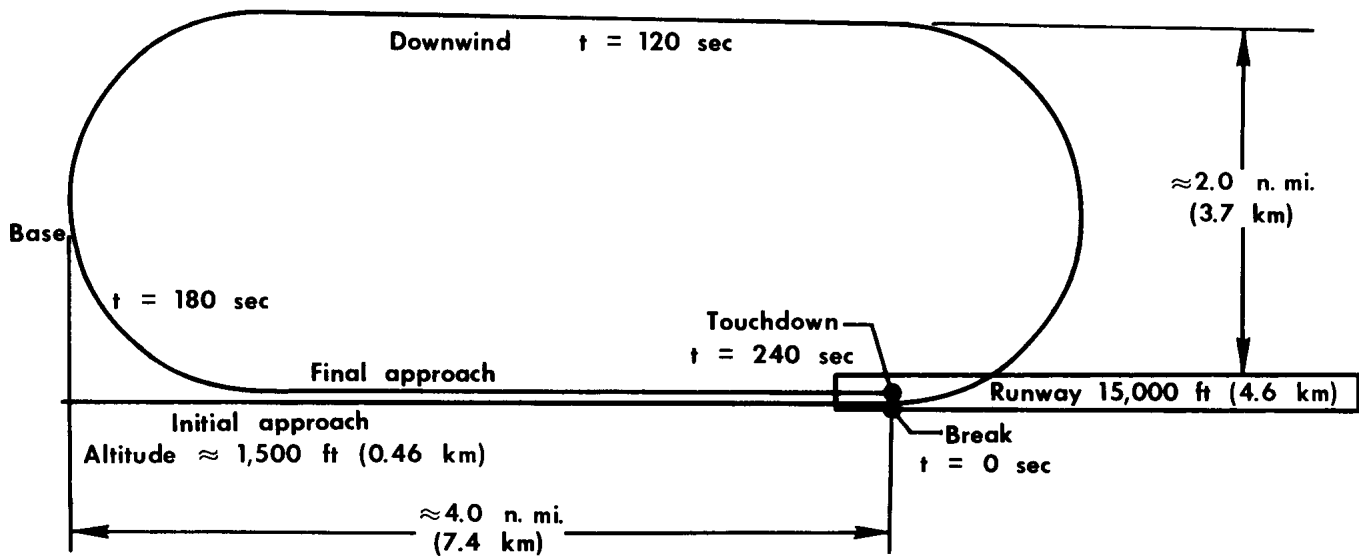


Figure 9.—Conventional approach.

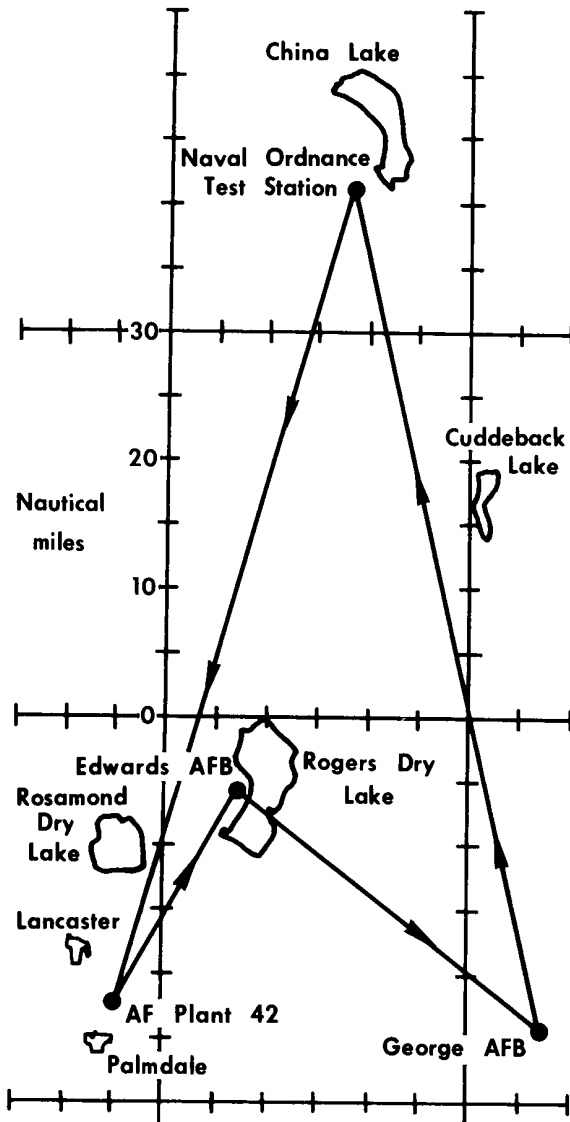


Figure 10.— Course flown on cross-country flight.

In addition to the preceding flights, two special flights were conducted, one at night and one cross-country. The night flight consisted of three low lift-drag-ratio landing attempts and two conventional landings. The cross-country flight consisted of navigating to three landing fields within a 100-mile (160-kilometer) radius of Edwards Air Force Base and making conventional landings at each field. The fields were: George Air Force Base, Naval Ordnance Test Station at China Lake, Calif., and Air Force Plant 42 in Palmdale, Calif. (fig. 10).

## RESULTS AND DISCUSSION

The data obtained during the program were qualitative comments by the pilots and the safety pilots. The responses to questionnaires given to the pilot and the safety pilot are summarized in appendix A. The intent of these questionnaires was to provide a basis on which to compare the comments of all the participating pilots. Additional pilots' notes are presented in appendix B. The pilot's and safety pilot's comments on the cross-country flight are presented in appendix C, and the pilot's notes on the night flight are presented in appendix D. The following discussions and results are based on these pilot opinions.

### General Comments

The 13 flights made during the program consisted of 33 low lift-drag-ratio low approaches, 8 low lift-drag-ratio landings, and 41 conventional landings in which the pilots used the viewing system with no assistance from the safety pilots. Also, the need arose to check out a pilot in the F-104B airplane. The checkout was accomplished with the check pilot using the viewing system, which provides an indication of the pilot's confidence in the system.

Several system deficiencies were noted that appeared to be common to all phases of flight. The most serious deficiency was the smallness (0.55 in. (14 mm)) of the exit pupil. Vibration while on the ground and acceleration forces while flying sometimes caused the pilot's eyes to shift momentarily out of the exit pupils. Also, while looking toward the extreme edges of the field, the pilot's normal eye rotation

frequently translated the pupils of his eyes to the outer edges of the exit pupil. The pilots also objected somewhat to the necessity of holding their heads in a fixed position so close to a rigid object.

Another system deficiency noted by the pilots was that basic flight information--airspeed, altitude, and power setting--was not presented in a readily accessible manner. To use the instruments available on the center panel, the pilots had to move out of the exit pupil. This was a relatively time-consuming operation compared with normal instrument cross-checks. When moving back into the exit pupils, the pilot's eyes had to adapt to the distortions and misalignments of the system. All of the pilots believed that they could have flown consistently better if this flight information had been provided in the optics.

### Takeoff and Climbout

The pilots and the safety pilots indicated that no severe problems were encountered during takeoff and climbout.

During the takeoff roll, heading reference was good, but the pitch reference required the pilot to adapt to the position of the objectives on top of the airplane. The changed pitch reference and the lack of a convenient airspeed reference resulted in poor control of rotation speed and angle. Also during takeoff roll, vibration of the system was bothersome.

During climb, the pitch reference was degraded somewhat because the horizon in climb attitude was at the bottom of the view field where the resolution was degraded. In addition, view to the side was not available for use as a pitch reference. During climb, roll and heading references were adequate. One pilot even thought that roll and yaw cues were better through the optics.

### Landings

During the program, 49 landings were performed. As indicated by the safety pilot's comments, most of the ratings were in the good-to-acceptable range. Also, the pilots, as indicated by their responses to the questionnaires and their other comments, were generally satisfied with their performances.

Landings did, however, indicate the major limitation of the system--a lack of adequate field of view to the sides. As indicated in appendix A by both the subject pilots and the safety pilots, judging position in the pattern relative to the runway was difficult when the runway was not in the field of view. To avoid this limitation, the pilots flew patterns with long final approaches and used memorized landmarks around the local airfield. This problem was graphically demonstrated during the cross-country flight; the pilot was not familiar with the area around the airfields visited and because of air-traffic-control procedures was forced to fly a tight pattern.

On six of the approaches, including both conventional and low lift-drag-ratio approaches, the pilots were allowed to use the side windows of the aircraft for position reference. On the low lift-drag-ratio approaches this was a great aid, and only a few transfers were made between the optics and the windows. During the conventional

approaches, many transfers were made. Since each transfer takes a relatively long time, the window-optic combination was not as useful in the conventional approaches as in the low lift-drag-ratio approaches.

Another problem that was particularly evident during the approach and landing phase of the flights was the difficulty in transferring to the basic flight displays and back to the optics. This generally resulted in less frequent cross-checks and, thus, larger than normal airspeed excursions. The pilots also noted that on their first landings they would level out about 5 feet (1.5 meters) above the ground.

### Night Flying

On the flight conducted to evaluate the optics during night operations, three low lift-drag-ratio approaches were made, with one approach carried to touchdown. Additionally, two conventional approaches were performed and carried to touchdown.

Basically, the night flying amplified the problems experienced during daytime flying. Because of loss of light in the system and the lack of view to the sides, navigation in the pattern was exceedingly difficult, which resulted in poor and inconsistent patterns. Also, as a result of the light loss, attitude control when flying toward the darker parts of the desert was very poor.

In spite of the problems encountered in the pattern, once the runway was sighted on final approach, the landings proceeded normally with no unusual problems.

The pilot believed that, if an inserted display of attitude and flight parameters, vision to the side, and better resolution were provided, consistently safe and acceptable night approaches and landings could be performed.

### Stereoscopic Effects

As shown in figures 5 and 6(a), the objectives were located 15 inches (0.38 meter) apart on the top of the aircraft. In using the system, the pilot's eyes are effectively located in this position, which yields the impression shown in figure 4.

While landing, rolling out, and taxiing, several anomalies were noted which imply that stereoscopic vision plays a significant role during these phases of operation.

During landing the pilots consistently leveled off about 5 feet (1.5 meters) above the ground when anticipating touchdown. While on the ground, the pilots thought they were traveling considerably slower than their actual speed, which resulted in high taxi speeds. This was noted particularly at night when other depth-perception cues were not present. On one occasion, the pilot anticipated performing a  $180^\circ$  ( $\pi$  radian) turn on the runway while still traveling at 130 knots (66 meters/second). Both of these characteristics can be explained by the enhanced stereoscopic effect resulting from the wide objective separation. As shown in figure 11, an object a distance  $L$  from the observer will result in an eye-convergence angle  $\alpha$  that depends on the eye (or objective) separation  $2S$  according to the relation  $L = \frac{S}{\alpha}$ , assuming small angles. As

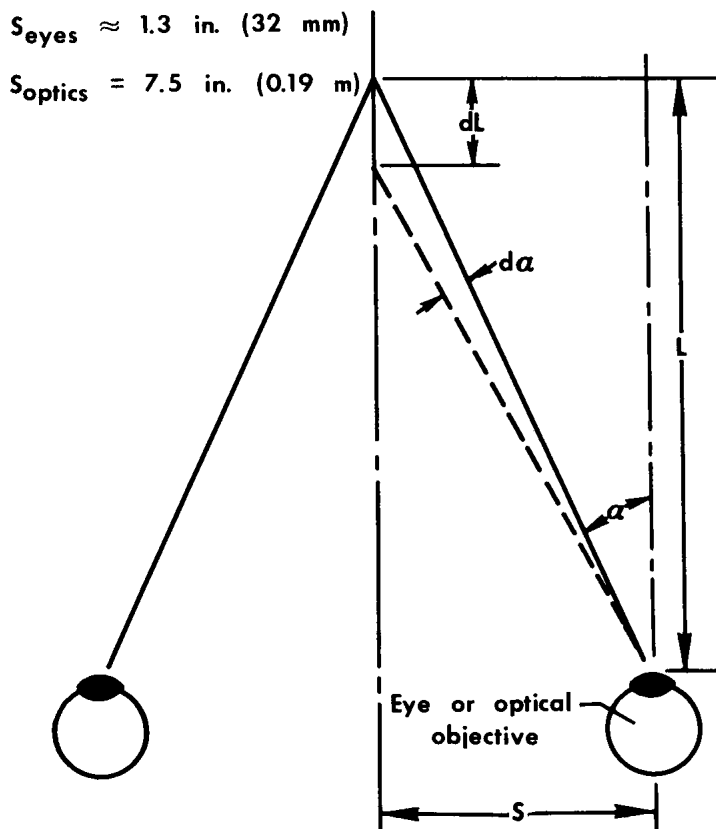


Figure 11.— Sketch of stereopsis.

shown, the eye and mind interpret distance by the relation

$$L_{\text{apparent}} = \frac{S_{\text{eye}}}{\alpha}$$

The problem that arises with the optics is that

$$L_{\text{actual}} = \frac{S_{\text{optics}}}{\alpha}$$

or

$$\frac{L_{\text{actual}}}{L_{\text{apparent}}} = \frac{S_{\text{optics}}}{S_{\text{eye}}}$$

Simply stated, the object appears closer than it actually is by the ratio of objective separation to eye separation. Differentiation of the distance equation yields the velocity relationship

$$\frac{S}{\alpha^2} \frac{d\alpha}{dt} = - \frac{dL}{dt} = -V.$$

By using the same line of reasoning as in the distance case, objects also appear to be moving slower by this same ratio,  $\frac{S_{\text{optics}}}{S_{\text{eye}}}$ .

### Operational Problems

Several operational problems were encountered with the optics. They are presented herein not as program results but as items to be avoided in the design of future systems.

System alinement and proper pilot head position were difficult to achieve, since the eyepieces and relay sections were adjusted independently of the objectives. This resulted in the optical axes of the eyepieces not necessarily being parallel to those of the objectives when adjustments were made for interpupillary distance. This lack of alinement appeared as rotations of the individual field of view. The converse was also true; in adjustments for zero image rotation, it was difficult to maintain the proper interpupillary distance. This feature resulted in an alinement procedure that is much too tedious and time-consuming for normal aircraft operations with more than one pilot.

System vibration was encountered that resulted in a rather severe loss of vision while the aircraft was on the ground. During the early phases of the program,

vibration was sufficient to alter the preflight alinement of the system and make it necessary to use additional clamps on the objectives.

The system was difficult to keep optically clean because of (1) bugs and dirt on the domes and (2) paint chips from the prisms and mirror mountings collecting on the lenses. Of the two, the bugs were the greatest problem, since each bug would blur about a  $10^\circ$  (0.17-radian) diameter section in the field of view.

## CONCLUSIONS

Flight tests of a wide-angle, indirect optical viewing system as a means of providing pilots of a high-performance jet aircraft with visual reference resulted in the following conclusions:

1. Safe and acceptable performance in all phases of daylight visual flight could be achieved with the use of the viewing system.
2. The system, in its present form, is considered to be unusable for night operations because of large light losses and degraded resolution.
3. Pitch-attitude sensing in daytime flight with the viewing system was marginal during climbing flight. This degraded pitch-attitude sensing was due to the poor resolution at the bottom of the field and the lack of view to the sides. Roll and yaw attitude sensing were satisfactory during daytime flight.
4. Enhanced stereoscopic vision resulted in conflicting distance and motion cues but did not prevent successful operations.
5. Lack of view to the side degraded all circling approaches.

## RECOMMENDATIONS

On the basis of the experience with the system and the deficiencies observed during this evaluation, the following features are recommended for consideration in the design of future short-eye-relief optical viewing systems:

1. View to the side of the aircraft to provide the pilot with the capability of performing circling approaches comfortably.
2. Display of basic flight parameters in the optical field to reduce the number of transfers of vision out of the optics.
3. Display of aircraft attitude in the optical field to improve pilot performance during night flying.

4. Larger exit pupils to prevent the pilot from losing the view during in-flight acceleration and vibration.

Flight Research Center,  
National Aeronautics and Space Administration,  
Edwards, Calif., August 12, 1966.  
125-19-01-02-24



## APPENDIX A

### SUMMARY OF QUESTIONNAIRES

#### PILOT QUESTIONNAIRE

##### General Questions

1. Was the visual field ever blurred due to vibration of the optics?

First flight:

Pilot

- A Yes, slightly on takeoff and significantly on landing.
- B Yes, mainly on the runway. Frequently out of focus due to head position.
- C Yes, during takeoff roll and in light-moderate turbulence at low altitude.
- D Yes, takeoff primarily; however, flight was made in the late afternoon and considerable turbulence was encountered.
- E Yes, most pronounced during takeoff and landing roll.
- F Yes, during landing roll during nosewheel shimmy.

Second flight:

Pilot

- A Yes, slightly on takeoff and landing but not during flight.
- B Very little. Ground only and then not much.
- C [Did not make second flight.]
- D Yes, takeoff and at low altitude due to moderate turbulence.
- E Yes, most noticeably during landing and takeoff roll. Vibration on the ground and in flight gives the impression of a degradation of focus.
- F Yes, in turbulence.

2. Did you experience any extreme discomfort due to being forced to maintain a set head position with respect to the eyepieces?

First flight:

Pilot

- A No.
- B No.
- C No.
- D Not extreme; however, the flight duration of 45 minutes is as much as I care to tolerate.
- E No, except my jaw was sore after the flight.
- F Position was tiring, but no extreme discomfort.

## APPENDIX A

Second flight:

Pilot

- A No.
- B No.
- C [Did not make second flight.]
- D No.
- E No.
- F No.

3a. Did you purposely or accidentally lose the exit pupil at any time during the flight?

First flight:

Pilot

- A Yes. Interpupillary distance was set too narrow, and I quite often lost the left exit pupil while centering the right one.
- B Yes, once only inadvertently, adjusted the recorder in my pocket. Also every time I cross-checked instruments.
- C Yes, I had to move out of the eyepieces to see altitude and airspeed.
- D I would estimate that I had both exit pupils less than 10 percent of the time. I had one clear one about 30 percent of the time and poor vision in both 70 percent of the time.
- E Yes, purposely.
- F Yes, particularly in rough air and when trying to cross-check airspeed and altitude.

Second flight:

Pilot

- A No.
- B Purposely, to cross-check airspeed.
- C [Did not make second flight.]
- D Yes, both, but, due to better adjustment, no problem reacquiring.
- E No.
- F Yes, in turbulence and in approaches when pulling "g" and occasionally when trying to cross-check instruments.

3b. If so, was reacquisition of the pupil at all difficult? And, what was the cause of this loss (turbulence, distraction, reference to the instruments, high g loads, etc.)?

First flight:

Pilot

- A No, see question 3a.
- B No.
- C No.

## APPENDIX A

- D      Reacquisition of even one pupil was difficult. Vibration and turbulence prevented me from getting into the ground-adjusted position. The mask and helmet also caused problems in getting back into a good position due to interference with optic structure.
- E      No.
- F      No, see question 3a.

Second flight:

Pilot

- A      No.
- B      No.
- C      [Did not make second flight.]
- D      See question 3a.
- E      No.
- F      Sometimes difficult to get back in focus.

4. On making turns, was the acquisition of heading references appearing at edges of the view field a problem?

First flight:

Pilot

- A      Yes.
- B      No.
- C      No, general area orientation was quite simple. Very easy to point it just where I wanted to be going.
- D      No.
- E      No.
- F      Yes, eyes were too far back.

Second flight:

Pilot

- A      Yes, optical quality is poor.
- B      It is an effort, partly because of resolution.
- C      [Did not make second flight.]
- D      No.
- E      Yes, because of the poor resolution at the edge of the field of view.
- F      Yes.

5. Was lack of normal fuselage and wing-tip reference noticeably troublesome?

First flight:

Pilot

- A      Not at all.
- B      No, since fuselage is in the field.
- C      No.
- D      No, some tendency to fly at higher nose attitudes than usual.
- E      No.

## APPENDIX A

- F No, longitudinal attitude was a little more difficult to adjust accurately.

Second flight:

Pilot

- A No.  
B No, references very good.  
C [Did not make second flight.]  
D No.  
E No.  
F No.

### Takeoff and Climbout

1. Did you experience any difficulty holding heading during takeoff roll?

First flight:

Pilot

- A No.  
B No.  
C No, quite easy in spite of aircraft vibration causing some distortion.  
D No.  
E No, this is probably one of the easier tasks.  
F Did not take off initially; on touch and go landings, heading control was no problem.

Second flight:

Pilot

- A No.  
B No.  
C [Did not make second flight.]  
D No.  
E No.  
F No.

2. Was downward vision adequate for establishing and maintaining proper pitch angle on climbout?

First flight:

Pilot

- A Yes.  
B More than adequate in a shallow climb; inadequate in steep climb.  
C Yes, both in afterburner and military.  
D Yes.

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- E I don't know why, as yet, but pitch attitude is difficult to judge. I flew the same climb schedule as the one flown when I was safety pilot. The pitch attitude seemed much lower through the optics; in fact, I rotated to a higher pitch angle than I desired, yet it looked low.
- F Attitude control (longitudinally) was slightly difficult to establish accurately.

Second flight:

### Pilot

- A Yes.
- B Fair.
- C [Did not make second flight.]
- D Yes.
- E Yes, but here again the climbout pitch angle appeared to be lower than when looking out the window.
- F Not as good as if normal vision was used.

3. Was your view of the horizon adequate at higher pitch angles for maintaining wings-level attitude?

First flight:

### Pilot

- A Yes.
- B Yes, up to about 15° (0.26 radian) pitch attitude.
- C Up to 20° (0.35 radian) pitch attitude.
- D Yes.
- E Keeping the wings level was never a problem. In fact, it seems that visual roll cues are amplified through the optics. Is this possible?
- F Yes.

Second flight:

### Pilot

- A Not evaluated.
- B Not very good, but okay when a conscious effort is made.
- C [Did not make second flight.]
- D Yes.
- E Yes.
- F Yes.

## Maneuvers

1. On making turns, was holding a given roll angle difficult, once established?

First flight:

### Pilot

- A No.

## APPENDIX A

- B No.
- C Not bad within  $\pm 5^\circ$  ( $\pm 0.09$  radian).
- D No.
- E No, but pitch reference was difficult to determine during turns. I had to cross-check the altimeter much more frequently during turns. A rate-of-climb indicator would be very helpful.
- F No, although not quite as good as regular flying.

Second flight:

### Pilot

- A No.
- B No.
- C [Did not make second flight.]
- D No.
- E No, but maintaining altitude in the turn is rather difficult.
- F Not bad.

## Approach and Landing

1. Did you have any problems maintaining proper approach speed, cross-checking between the exterior view field and instruments?

First flight:

### Pilot

- A Low lift-drag-ratio approaches were no problem. Resented having to cross-check airspeed on normal landings because I had no peripheral vision.
- B Some, not too bad. Would be bad if there were a lot of traffic or radio calls.
- C Not a problem, it was just a pain!
- D No.
- E Yes, I continually got slow in the approach.
- F Not much.

Second flight:

### Pilot

- A Yes, cross-check takes you out of the optics.
- B No.
- C [Did not make second flight.]
- D No.
- E No problem during the touch and go's, but I did experience some problem with speed control during the low lift-drag-ratio approaches. I tended to get slow at the  $180^\circ$  ( $\pi$  radian) position.
- F Some difficulty.

2. Did downward vision seem adequate for establishing high- and low-key points?

## APPENDIX A

### First flight:

#### Pilot

- A No.
- B Would like much more.
- C No, worst case is low key, where I found it hard to get proper abeam position.
- D Yes, but lateral vision is the important one in pattern, and this was marginal and probably would not be adequate at a strange field.
- E No, normally I do not use landmarks for low lift-drag-ratio approaches. Therefore, I had no preplanned reference points. This was a definite disadvantage.
- F No, particularly high key.

### Second flight:

#### Pilot

- A No.
- B Fair.
- C [Did not make second flight.]
- D Yes.
- E Yes, if you roll the airplane at high key.
- F No.

### 3. How well could you judge flare-point altitude?

#### First flight:

##### Pilot

- A Excellently.
- B As well as direct visual.
- C Fairly consistently leveled off 5 feet to 10 feet (1.5 meters to 3.1 meters) high.
- D Surprisingly well.
- E Quite well. I think, in general, flare-initiation altitude was a bit high, but if one keeps the speed on the high side, this does not present a problem.
- F Not quite as good as normal.

#### Second flight:

##### Pilot

- A Just as well as without optics.
- B Very well.
- C [Did not make second flight.]
- D Fair, tended to flare high, but this was possibly due to M-2 lifting body approach practice.
- E Not as well as looking out, but I was satisfied with this part of the approach.
- F Not quite as good as normal.

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4. Did you notice any exaggerated stereo-vision effects during flare and post-flare?

First flight:

Pilot

- A Tended to "land slightly high," i.e., thought I would touch down sooner than I actually did.
- B No.
- C No, except poor height judgment.
- D No.
- E No.
- F No.

Second flight:

Pilot

- A Okay during flare. After flare there is an impression that the aircraft is about 5 feet (1.5 meters) lower than is actually the case.
- B No.
- C [Did not make second flight.]
- D Postflare height was misjudged.
- E No.
- F No.

5. Did performance on landings seem to improve as you gained experience with the optics?

First flight:

Pilot

- A Yes.
- B No.
- C Yes.
- D Can't say.
- E Yes, I think the important factor is that one's confidence level goes up.
- F Yes.

Second flight:

Pilot

- A Yes.
- B Yes.
- C [Did not make second flight.]
- D Yes.
- E Yes, I am sure that experience plays an extremely important part in satisfactory performance.
- F Some.

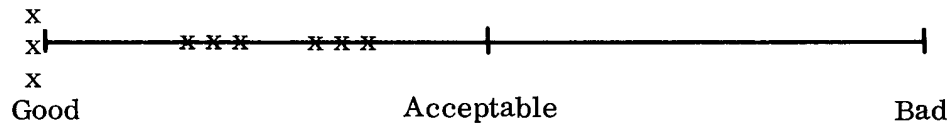


# APPENDIX A

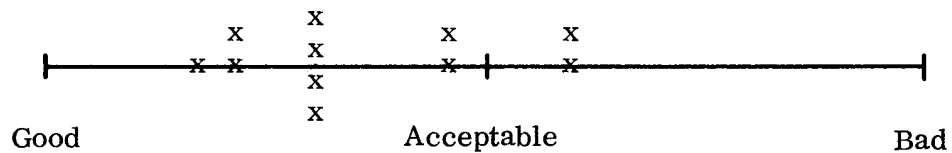
## SUMMARY OF SAFETY-PILOT QUESTIONNAIRE

### Safety-Pilot Ratings

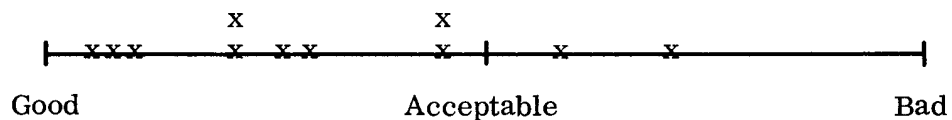
#### 1. Takeoff roll rotation



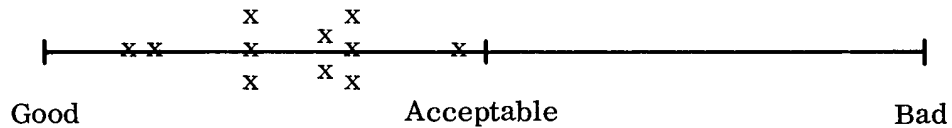
#### 2. Establishing and maintaining rate of climb



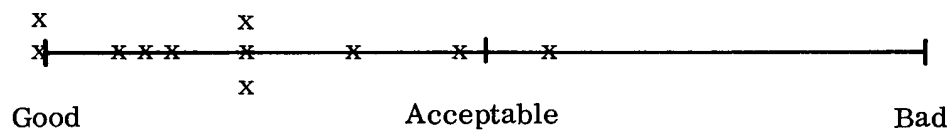
#### 3. Straight-and-level flying, holding altitude



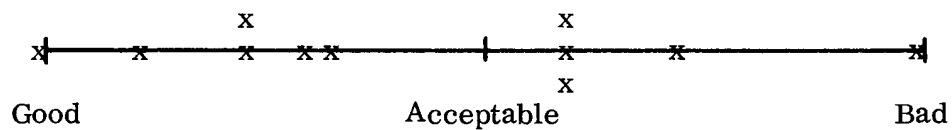
#### 4. Holding bank angles, turning



#### 5. Establishing and maintaining glide slope, approach speed

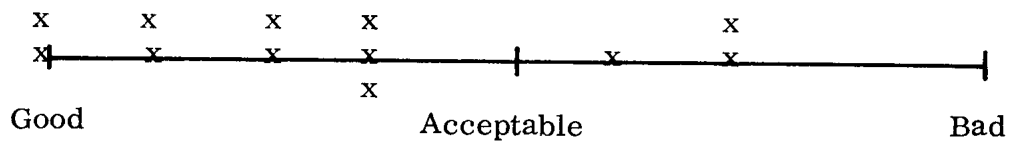


#### 6. Establishing high- and low-key points

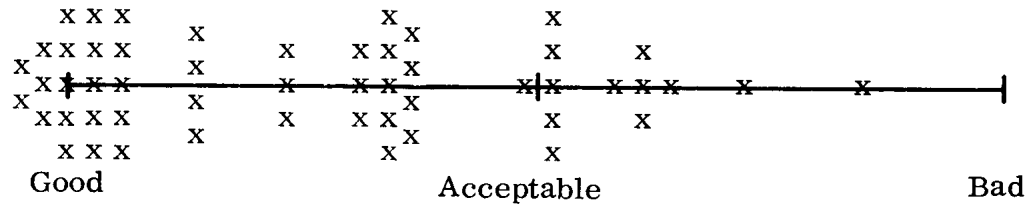


## APPENDIX A

## 7. Judging altitude preflare and postflare



8. Overall landing performance (each landing rated separately)



## APPENDIX B

### ADDITIONAL PILOTS' FLIGHT NOTES

#### PILOT A - FIRST FLIGHT

Upon entering the cockpit, it was noticed that the exit-pupil interpupillary distance was set slightly too small for the pilot. Since correction of this would have delayed flight, it was accepted. The maladjustment required that the pilot's eyes be held slightly closer than the normal eye-relief distance of 0.83 inch (21 millimeters) in order to have the full field of view through both optics. This maladjustment also reduced the lateral allowable head movement and is felt to have degraded the pilot's performance slightly but not significantly. It did, however, illustrate the necessity of having this adjustment properly set for the individual pilot prior to each future flight.

While the safety pilot was taxiing to the runway, the project pilot observed that through the optics the horizon appeared to slope gradually up, perhaps  $5^\circ$  (0.09 radian), on each side of the center due to misalignment. This phenomenon proved not to be a problem in flight.

The project pilot made a normal and satisfactory takeoff and climb to 25,000 feet (7.6 kilometers). Turns and one aileron roll were performed without complications.

One straight-in and two circular low lift-drag-ratio approaches were performed to lakebed runway 18 (Edwards Air Force Base). None of the approaches was flown to touchdown but all appeared that they would have resulted in satisfactory touchdowns. One circular low lift-drag-ratio approach was performed to the main runway, terminating in a satisfactory landing.

Three landings were performed on the runway with the takeoff-flap setting. All touchdowns were smooth, but were quite long (2000 to 5000 feet (0.61 to 1.52 kilometers) down the runway). This touchdown dispersal could be reduced considerably with practice and the resultant increased confidence in the use of the optics.

Height and rate-of-sink perception were excellent during all approaches, with the exception of the last few feet prior to touchdown, where the impression was that the F-104B was closer to the ground than it actually was. This presented no problem in acquiring smooth touchdowns but did result in touchdowns 500 to 1000 feet (0.15 to 0.31 kilometer) past the predicted touchdown point.

Difficulties in circling approaches due to restricted ( $130^\circ$  (2.3 radians)) horizontal field of view were exactly as anticipated from previous participation in a restricted-field-of-view program with a T-33 airplane. Using the optics only, there was no way to precisely locate high-key position on the circular low lift-drag-ratio approaches. This position had to be located by flying airspeed for 15 seconds after the runway disappeared from view approaching high key. The runway was reacquired in view briefly on the downwind leg but disappeared again prior to the final turn, which had to be commenced by estimate. The runway was not seen again until only  $70^\circ$  or  $80^\circ$  (1.2 radians or 1.4 radians) of turn remained, and there was some tendency to

## APPENDIX B

overshoot the final turn. These difficulties generally were repeated in the power-on approaches and emphasized the requirement for side vision when accomplishing circling approaches.

Location of the optics with respect to the seat was excellent; the pilot was able to maintain his eyes in the exit pupils while assuming a normal flying position. The headrest and the oxygen-mask retainer combined to provide good protection for the pilot's eyes and cheekbones.

The altimeter and airspeed indicator were conveniently located on the center pedestal and required very little head and eye motion for cross-check. The desirability of one additional cockpit instrument was ascertained; a slaved gyro would be helpful in determining downwind leg heading, particularly in an area unfamiliar to the pilot.

The project pilot flew the entire mission from takeoff roll to completion of final landing roll and at no time removed his eyes from the optics except to cross-check instruments.

### PILOT B - SAFETY PILOT COMMENTS ON FIRST FLIGHT OF PILOT A

All maneuvers on this flight, including takeoff and some of the taxiing, were done from the rear cockpit. In all respects, piloting performance was as good as when using the windows, with the following exceptions:

1. Handling of power in all flight regimes, but especially circling low lift-drag-ratio approaches and final approaches in conventional patterns, showed evidence of less frequent cross-check of airspeed, power, and altitude than is usually the case for Pilot A.

2. High-key and low-key positions in circling low lift-drag-ratio patterns, as well as the  $180^\circ$  ( $\pi$  radian) point in conventional approaches, were located less precisely and consistently than would normally be the case. This was because the pilot was using the optics alone and was not able to see the runway at high key or low key. Since the runway could not be seen from low key, there could be no judgment whether the approach was high or low at that point. Similarly, the pilot did not know whether he was high or low on the glide path until half through the base turn on conventional patterns. This caused all final approaches to be steep and caused touch-downs to be long.

The accurate perception of altitude during flare and landing both for conventional and for simulated flameout patterns was particularly noteworthy. Directional control during landing and takeoff was excellent without the yawing or crabbing frequently associated with back-seat takeoffs or landings. The safety pilot made only one correction, that of modifying the gear-down speeds due to an airspeed-indicator error either in the front or the rear cockpit.

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### PILOT B - FIRST FLIGHT

The entire flight was considered easy, and there was no trouble in achieving desired touchdown points or projected touchdown points on the last two circling low lift-drag-ratio approaches and the four conventional landings. Based on the experience of Pilot A in the first flight, it was considered that attempts to flare prior to being over the runway would not entail unreasonable risk. The first simulated flameout pattern resulted in a projected touchdown point approximately 2000 feet (0.61 kilometer) long because of the poor determination of high-key position.

The next two simulated flameout approaches were made by placing the high-key point deliberately long and high to allow the approach end of the runway to be seen through the optical system at low key. Touchdown points were satisfactory.

Approaches to the main runway for conventional landings were made in a normal manner except for using the magnetic compass in the front cockpit for downwind reference. Conventional patterns were deliberately flown wide, with long final approaches, similar to the no-flap patterns. Touchdowns (on four landings) were between 1500 to 2300 feet (0.46 to 0.70 kilometer) from the approach end of the runway, which is normal for Pilot B. Patterns on which the landing-flap settings were used resulted in longer touchdowns because power cross-check was required.

Perception of rate of descent on a short final approach, estimation of flare point, and prediction of touchdown were, if anything, better than by direct visual contact because of the far greater field of view directly down and forward afforded by the optical system.

The following comments are made in the order in which they came to the pilot's attention during flight. It should be noted that these comments represent undesirable features of the optical system which are either of a trivial or "housekeeping" nature that could be easily remedied on the next design or eliminated by enlarging the field of view.

1. The field of view forward and down was not adequate for horizon reference on a steep climbout, since such reference is usually obtained by looking  $45^\circ \left( \frac{\pi}{4} \text{ radian} \right)$  to either side of the cockpit. Perception of rate of climb near the ground was poor and was marginal at altitude.

2. Vibration was bothersome when the helmet touched any part of the optical supporting structure or the pads.

3. Focus was poor unless adjustment of the pilot's eye position was made frequently.

4. Flap indicators were hidden by the stick in most normal stick positions.

5. Airspeed indicator and altimeter were dark by contrast to the optical picture when flying toward the sun and, hence, were difficult to see.

## APPENDIX B

6. In spite of the difficulty in cross-check, it was not difficult to keep airspeed on final approach to within  $\pm 5$  knots ( $\pm 2.6$  meters/second) of the desired. If there were distractions, however, this might not be possible.

7. Approaches made with landing-flap settings were difficult from the point of view of cross-check, since power had to be cross-checked on these approaches in addition to airspeed.

8. The aircraft could have been easily stopped before reaching the center taxiway on the Edwards Air Force Base main runway. However, the center taxiway appeared to be much farther away than it really was so that braking was not started until the airspeed had decreased below 90 knots (45 meters/second). This made it necessary to turn around on the runway and taxi back approximately 30 feet (9.2 meters).

### PILOT E - COMMENTS ON FIRST AND SECOND FLIGHTS

For some reason, the pilot was not positive of his pitch attitude after nose-gear lift-off during the takeoff rotation.

Some difficulty was encountered in achieving the desired focus during the final phase of the circling low lift-drag-ratio approaches due to the rapid rate of closure with the aim point. This was not nearly as much a problem during the touch-and-go landings because of the relatively low vertical velocity prior to touchdown.

High crosswinds at high key further complicated the problem of approaching without having a side window. A perfect "mechanical" approach could be flown to the low-key point, but, without some additional references, the crosswind would result in drift to the side.

A higher high-key position and a slightly wider pattern might be a better way to use the optical system.

Long final approaches made the conventional landings more comfortable.

## APPENDIX C

### PILOT AND SAFETY PILOT NOTES ON CROSS-COUNTRY FLIGHT

#### PILOT B

The purpose of this flight was to investigate the use of the optics for cross-country flight and visual approaches and landings at three unfamiliar fields. The flight plan was to perform a touch-and-go landing at George Air Force Base, the Naval Ordnance Test Station (NOTS) at China Lake, Calif., and at Air Force Plant 42 in Palmdale, Calif., and to make a full-stop landing at Edwards Air Force Base (fig. 10). The pilot had landed previously only on the Edwards runway. Navigational aids or straight-in approaches were purposely not used.

The approach at George Air Force Base was uneventful. On this approach, section lines on the ground and the magnetic compass in the front seat were used. This compass can be used when the aircraft is straight and level but cannot be used during the turns. Touchdown was somewhere between 1000 and 2000 feet (0.31 and 0.61 kilometer) from the threshold. Pilot E felt that the aircraft was somewhat low over the overrun; however, with a fuel load in excess of 5000 pounds (22,200 newtons), a successful full-stop landing without the drag chute would necessitate an approach of this nature.

The pattern was flown with takeoff flaps because of the inadequate go-around capability with the landing-flap setting at the higher fuel weights. Height judgment near the ground during the flare was not as good as normal in more familiar surroundings.

The approach to NOTS was complicated by the fact that the tower requested a tight pattern and specified no flight over the housing area. This necessitated a final approach of 4000 feet (1.22 kilometers) or less, which is completely inadequate in an F-104 with a 3,500-pound (16,000-newton) fuel load under any condition. Because of the inadequate go-around capability with the landing-flap setting, takeoff flaps were used.

Navigation on the downwind leg proved to be no problem; however, the turn to final approach was a problem. Even while maintaining 240 knots (120 meters/second) indicated, the aircraft was still at an undesirably high angle of attack. On this approach, lack of a heading reference during the turn to final approach and lack of air-speed or angle-of-attack reference within the field of view added considerable difficulty. The primary problem at NOTS, however, was not the optical system but the non-standard approach required by the tower, which was incompatible with an F-104B at that fuel weight.

Coming over the overrun, Pilot E commented that the aircraft was much too low. However, a successful full-stop landing without a drag chute on such a short runway at that fuel weight would require an approach in which the wheels were inches above the overrun. Because of Pilot E's comment, power was added over the overrun, thus

## APPENDIX C

preventing a touch-and-go landing. No pitch correction was made. On the next pattern, the tower again requested a close pattern. The turn to final approach was at as high an angle of attack as possible and was overshoot. A go-around from a short final approach was elected.

The approach and landing on runway 07 at Air Force Plant 42 was uneventful since a wide pattern was allowed. By that time, Pilot E was becoming apprehensive about low flares over the overrun, so the approach was flown as Pilot E did the day before, that is, by maintaining 90-percent power to touch down with landing flaps and touching down at 170 to 175 knots (87 to 90 meters/second), 30 knots (15 meters/second) faster than the normal landing-flap touchdown speed. This technique is not acceptable except on very long runways, since it adds about 4000 feet (1.2 kilometers) to the stopping distance above that required for a normal landing with landing-flap setting. Again, altitude judgment above the runway was not as good as in familiar surroundings.

Generally, the flight was a particularly and probably unreasonably severe test of the optics, since neither a heads-up display nor navigational information was available and straight-in approaches were not used. The situation at NOTS was essentially an impossible one for an F-104 at that fuel weight, regardless of whether or not optics were used. Even here, however, a heads-up display of heading, airspeed, and angle of attack would have made a great deal of difference. Also, use of side windows would have helped.

For the first time, better resolution might have assisted in determining height above the ground when close to touchdown. This was not nearly as evident at Edwards Air Force Base, where the size of objects on the ground are known. The resolution of this system may be adequate but head position was not properly maintained because of the necessity of performing other tasks.

### PILOT E - SAFETY PILOT COMMENTS ON CROSS-COUNTRY FLIGHT

The takeoff, climbout, and cruise to George Air Force Base were normal. Pilot B was able to navigate satisfactorily utilizing the optics. He remarked that the section lines and roads that were parallel to and perpendicular to the runway aided in flying the approach pattern. The landing was satisfactory with a tendency to flare a bit too high.

The navigational task to NOTS was performed well. On approaching, the tower requested a hold 9 miles southeast of the field. This approach caused a little trouble, probably because Pilot B did not have a compass and directional orientation was difficult with a reduced field of view. The control tower placed two severe restrictions on the traffic pattern: (1) the downwind leg had to be quite close to the active runway to remain clear of a firing range, and (2) the final approach was considerably shortened to remain clear of a housing area.

The two approaches to NOTS were very difficult. The restrictions imposed by the tower caused the approach turn to be very tight and the final approach leg to be extremely short. Angle of attack was undesirably high during both approaches and reached a very high value on the second approach. On both occasions, the final leg was overshoot. On the second attempt the overshoot was sufficient to require an



## APPENDIX C

immediate go-around. A landing was made during the first attempt, although the safety pilot made a back-stick input during the approach to correct for a too-low situation just short of the runway.

The rest of the flight was normal, although Pilot B did experience some concern about lateness in visually picking up the runway during the final approach at Plant 42. At Edwards, the flare was a bit high, resulting in a late touchdown. Rollout was to the end of the runway.

In summary, it appears that at an unfamiliar field the pilot spends a great deal more time determining geographic position; consequently, less time is spent "flying the airplane" and observing flight parameters. This could lead to dangerous flight conditions. The difference in time spent "looking out" of the airplane at a strange field with and without the optics would be interesting to determine.

A straight-in approach at NOTS probably would not have caused any problem. However, the approach required was essentially impossible.

## APPENDIX D

### PILOT A FLIGHT NOTES ON NIGHT FLIGHT

This flight, an evaluation of the optics during twilight and darkness, had been preceded by proficiency flights in an F-104N the previous night and one night during the preceding week. These flights had indicated a requirement for beginning power-off landing flare by use of the altimeter, at least for the pilot's level of night proficiency. If the flare was performed by intuition, it was commenced early, causing touchdown to occur too slow and too far down the runway. In the F-104N this appeared to be the only item that made night landings different from daylight landings.

The evaluation flight was preceded immediately by a daylight proficiency flight in the test aircraft. Four power-off and two power-on approaches were performed without difficulty.

Takeoff was at 2005 hours, 15 minutes after official sunset. The debilitating effects of light loss in the optical system were immediately apparent; the horizon, which was almost masked by haze to the naked eye, was totally lost through the optics. Also, dry lakes used for navigation were lost in the twilight when the optics were used. The first power-off approach was successfully performed, but no landing was made due to conflicting traffic. This pattern was made with some twilight remaining.

While attempting to return to high key for a second power-off approach, the pilot mistook Lancaster, Calif., for Edwards, Calif. (fig. 10), and had to accomplish an additional  $360^\circ$  ( $2\pi$  radian) turn to get to high key after recognizing his mistake. The error is ascribed to the poor optical quality of the system; lights are so blurred as to change the character of a lighted community.

The second approach was flown to a successful touchdown, but considerable turning was required during the final approach to line up with the runway and to dissipate excess energy. The difficulty in accomplishing the power-off pattern is believed to be due to loss of navigation cues (particularly Rogers Dry Lake at Edwards Air Force Base) which had been available in the F-104N but were not present in the F-104B due to loss of light through the optics.

The third high key was successfully located, but final turn was too close in and was undershot. A successful landing flare was accomplished, but the landing was not made because the touchdown would have occurred within 2500 feet (0.76 kilometer) of the far end of the runway.

Two successful power-on approaches and landings were made. Pitch control in these patterns was substandard, probably due to poor pitch-attitude cues through the optics plus very limited flight instrumentation in the rear seat of the airplane. No other inadequacies were noted during the power-on approaches.

It was felt that if an optical system were to be used operationally it should possess optical quality sufficient to cause minimum distortion of lighted objects. Light loss would probably be inherent in any system, so terminal guidance would most likely be required for any vehicle landing by optics at night.

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